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(54) Title: A METHOD OF CALIBRATION FOR AN AUTOMATIC MACHINE TOOL
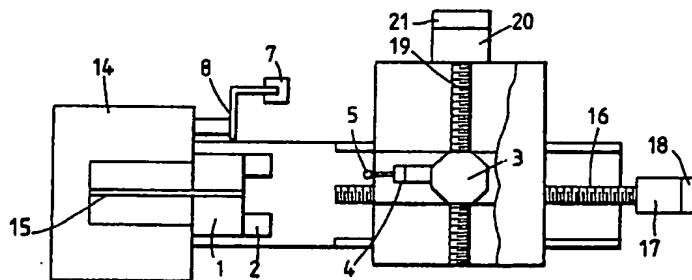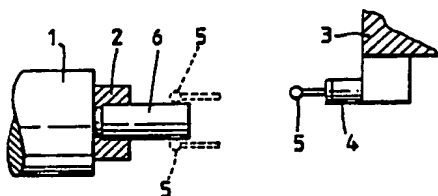
(57) Abstract

In an automatic lathe, a touch trigger probe (4) is calibrated (datumed) against an item (6) having a known reference dimension, instead of against the lathe chuck (2) or against a surface machined in a workpiece. The calibrated probe is then used to touch two diametrically opposed points of a feature (12) centred with respect to the axis of rotation of the chuck (2). From the mean of the co-ordinates of the two points touched, there is calculated an offset related to the difference between the assumed axis of rotation and the actual axis of rotation. This calibrates the machine to compensate for any drift between the actual axis of rotation and the machine's measurement origin.

A METHOD OF CALIBRATION FOR AN AUTOMATIC MACHINE TOOL

The present invention relates to a method of
calibration for an automatic machine tool, and more
particularly for a lathe.

5   In the machine tool art, it is known to use a "touch
trigger probe", of the kind described in US Patent
No. 4,153,998, to trigger data processing means to
produce an indication of x,y and z co-ordinates of a
stylus of the probe in response to the stylus touching
10   a surface. Such probes are moved relative to the
workpiece in a similar manner to the cutting tools
themselves (e.g. on a tool-holding turret) and may be
used both for checking the dimensions of a workpiece
after machining by the machine tool and for controlling
15   the machine tool during its machining of the workpiece.

The measurement indications of x,y and z co-ordinates
are taken with respect to a measurement origin of the
machine tool. Prior to use, the probe may be
20   calibrated or "datumed" by causing it to trigger

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against one or more reference surfaces at fixed
positions. This allows the calculation of "probe
offsets" between the effective contact surfaces of the
stylus and a nominal measurement position of the turret
5   or other tool-holder in which the probe is mounted.
These probe offsets are used to perform correction on
subsequent measurements taken with the probe. Assuming
the accuracy of the fixed reference position, such a
correction takes account of the difference between the
10 nominal measured position and the effective stylus
contact surface.

We have found that a potential inaccuracy in probe
datuming may occur in some machine tools if there is
15 inaccuracy of positioning between the reference surface
and the measurement origin. This may arise if there is
deformation of the bed of the machine tool, causing a
relative movement of the measurement origin. Such
deformation may occur, for example, as a result of
20 loading or thermal effects on the bed of the machine
tool.

In the case of a machining centre, such problems do not
normally arise, at least in the x and y axes, for the
25 following reason. The cutting tool spindle of a
machining centre is on the tool-holder, and hence its
axis of rotation is local to the probe. The effects of
machine bed deformation on the position of the
measurement origin therefore have the same effect on
30 both the measured position of the probe and on surfaces
of the workpiece cut by the cutting tool. It follows
that surfaces cut in the workpiece by the tool can be
used as reference surfaces to calibrate the probe
offset, since the effects of deformation then cancel
35 each other out and do not give rise to a problem. Such
techniques are described, for example, in US Patent

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No. 4,281,385 and British Patent Application
No. GB 2,108,715 A.

In the case of lathes, it is known to calibrate the
5   probe offset in the manner described above, using
reference surfaces provided on the workpiece-holding
chuck. See for example US Patent No. 4,382,215, and
"Users Handbook - Programs for Probes, Component
Inspection and Tool Datuming with Fanuc 6TB Control",
10   Part 3, pages 25-35, published in 1984 by Renishaw
Electrical Limited. However, we have found that this
gives rise to the above-noted problem due to machine
deformation. The problem cannot be removed simply by
datuming the probe against surfaces machined in a
15   workpiece by the use of the lathe, because the axis of
rotation of the chuck is remote from the tool holder
which holds the probe. Such datuming processes, we now
realise, involve an assumption that the position of the
axis of rotation of the chuck or workpiece can be
20   accurately known relative to the measurement origin.
In practice, this is not accurately known so if the
machine is subject to deformation, and the inaccuracy
is not cancelled out in the manner that it would be
with a machining centre, because the axis of rotation
25   is not local to the probe.

According to the present invention, there is provided a
method of calibration for an automatic machine tool
having workpiece-holding means which is rotatable for
30   machining a workpiece held therein, data processing
means, and a trigger probe, which probe can be
triggered against a point on the surface of the
workpiece, in response to which the data processing
means produces information representative of positional
35   co-ordinates of the probe at the trigger point, the
co-ordinates being with respect to a datum point which

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is based upon an assumed axis of rotation of the
workpiece, the method comprising:

(a) calibrating the probe, by triggering it against
at least one point on an item having a known dimension
5   and, using said dimension and a positional co-ordinate
of the or each trigger point as indicated by the data
processing means, computing a probe correction offset;
and

(b) calibrating the machine tool, by providing a
10   feature centred with respect to the actual axis of
rotation; triggering said probe against first and
second diametrically opposite points on said feature
with respect to the axis of rotation; and, on the basis
of the mean of respective positional co-ordinates of
15   the trigger points as indicated by the data processing
means, corrected by the probe correction offset,
computing an offset related to the difference, if any,
between the actual axis of rotation and the assumed
axis of rotation.·

20

The feature centred with respect to the actual axis of
rotation is preferably provided by machining the
feature into a workpiece, since this ensures
concentricity and obviates inaccuracies which can be
25   caused by datuming on a surface of the chuck (which may
become distorted owing to clamping loads).

The present invention will now be described, by way of
example, with reference to the accompanying drawings,
30   in which:

Figs. 1-4 are schematic diagrams for use in
explaining the principle of one aspect of an example of
the invention;

Figs. 5,6 and 7 are schematic diagrams for use in
35   explaining how measurements are made after a
calibration for a stylus dimensi n has been

accomplished;

Figs. 8,9,10b and 11 are schematic diagrams for use
in explaining the principle of a second aspect of the
example of the invention;

5   Figs. 14a,14b and 15 are schematic diagrams for use
in explaining an extension of the second aspect of the
example of the invention.

The following example of the invention first describes
a method for calibrating a touch trigger probe used
with an automatic lathe, by deriving the effective
(electronic) diameter of the spherical stylus of the
probe. It then describes a method of using the
thus-calibrated probe to calibrate for the actual

15   centre-line (axis of rotation) of the lathe.

Referring first to Fig. 1, reference numeral 1 denotes
the chuck of an automatic lathe having chuck jaws 2.
Reference numeral 3 denotes a tool turret of the lathe,

20   carrying a touch trigger probe 4 having a spherical
stylus 5. Reference numeral 6 denotes an item for
example a reference bar or cylinder, held in the jaws 2
as concentrically as possible and of known diameter
Dref. The stylus 5 of the probe 4 is caused to touch

25   the item 6 at two diametrically opposite points as
shown by broken lines Fig. 1. Referring to Fig. 2, if
X1 and X2 are the x-co-ordinates as measured by data
processing means coupled with the probe for the two
points of contact, then the effective (electronic)

30   diameter Db of the stylus (which is smaller than the
actual, physical diameter of the stylus), is given by:
$$Db = Dref - (X1 - X2)$$

The data processing means is programmed to effect a

35   calculation on the basis of the above equation to
produce an indication of the effectiv (el ctronic)

diameter of th stylus 5 for use in correcting
co-ordinate measurements on the basis of Db.

5   If the co-ordinate measuring system comprising the data
processing means and the probe has been calibrated with
respect to the centre-line (axis of rotation) of the
lathe, then a single touch method at a point whose
x-co-ordinate is measured to be X1 can be used to
obtain the effective stylus radius (Rb) by the
10   equation:

    $Rb = Rref - X1$, where $Rref$ is the known radius of
the item 6.

    The computation of the effective stylus diameter (or
15   radius) could be carried out with respect to an
internal bore in an item 6 held in the chuck jaws 2,
the bore being of known diameter Dref - see Fig. 3.
Again:

    $Db = Dref - (X1 - X2)$ or
20     $Rb = Rref - X1$ if the system has been calibrated
with respect to the centre-line of the lathe.

    As an alternative (due to machine constraints) to
calibration for stylus diameter (or radius) with
25   respect to an item 6 held in the jaws 2, an item for
calibration purposes may be used which is held by a
remotely mounted calibration arm - see Fig. 4. In Fig.
4, reference numeral 7 denotes an item of known
dimensions carried by a fixed or automatically
30   re-positionable arm 8. For greatest accuracy,
preferably the arm 8 can be swung so that the item 7 is
in the vicinity of the centre line of the lathe during
the calibration. It is swung out of the way
afterwards. Item 7 could, as shown, be a cube of known
35   thickness D, the effective diameter Db of the stylus 5
being given by:

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$$Db = D - (X1 - X2)$$

After the system has been calibrated for the effective
diameter or radius of the stylus 5, then the value of
5   the latter may be taken into account when using the
probe 4 to measure dimensions. Referring to Fig. 5, if
the internal diameter D1 of a bore in a workpiece 9 is
to be measured by touching the stylus 5 at two
diametrically opposite points of the bore, then D1 is
10   found by adding the diameter Db of the stylus 5 to the
diameter of the bore as actually measured by the system
comprising the probe 4 and the data processing means.
Referring to Fig. 6, if the external diameter D2 of a
workpiece 10 is to be measured by touching the stylus 5
15   at two diametrically opposite points, then the diameter
D2 is found by subtracting the diameter Db from the
diameter as actually measured by the system comprising
the data processing means and the probe 4. Where
diameter measurement is not possible directly by virtue
20   of machine constraints, a single touch method may be
used provided that the probe centre-line with respect
to the lathe centre-line has recently been upgraded.
For example, referring to Fig. 7, the radius R3 of a
workpiece 11 is found from the difference between the
25   radius as actually measured by the system comprising
the data processing means and the probe 4 and the
effective radius of the stylus 5; and the radius R4 of
the workpiece 11 is found by adding the radius as
actually measured by the system comprising the data
30   processing means and the probe 4 and the effective
radius of the stylus 5.

Incidentally, if the item with respect to which the
above computation to determine the effective diameter
35   (or radius) of the stylus 5 does not have its axis
parallel with the centre-line (axis of rotation) of the

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machine tool, then this needs to be compensated for in
computation of the effective diameter by ascertaining
the angle between the two axes and applying the cosine
principle to (X1 – X2) or X1.

5

There will now be described a method of calibrating for
the actual centre-line of the lathe. This might differ
from the assumed centre-line on the basis of which the
system comprising the data processing means and the
10 probe 4 provides co-ordinate information, for example
due to thermal or other effects. (In practice, the
co-ordinates are taken from an arbitrary measurement
origin of the system, which is normally assumed to be
fixed with respect to the centre-line; an assumption
15 which might be invalid at any given time because of the
thermal or other effects. Calibration as described
below compensates for this).

First, referring to Fig. 8, a workpiece 12 is turned on
20 the lathe using a tool to a diameter suitable for the
stylus 5 on the probe 4 to contact diametrically
opposite points, as shown by the broken lines in
Fig. 8.

25 Referring to Fig. 9, if:
      X1 is the x-co-ordinate of one point of contact as
measured by probe 4 and the data processing means;
      X2 is the x-co-ordinate of the other point of
contact as measured by the probe 4 and the data
30 processing means; and
      Xc is the assumed x-co-ordinate of the centre-line
of the lathe,
      then the error Xe in the system's assumption of the
x-co-ordinate of the centre-line of the lathe is given
35 by:
      $Xe = Xc - Xm$ where

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Xm = (X1 + X2)/2, namely the mean of X1 and X2.

Incidentally, the probe can be arranged so that its
principal axis is parallel or normal to the rotational
5 axis (centre-line) of the lathe - see Figs. 10a and
10b. This applies also to the earlier described method
of calibration for stylus diameter of radius.

Once the error Xe in the assumed centre-line has been
10 computed, this can be used by the data processing means
to directly modify the offset with respect to a datum
point with respect to which position is defined, or by
using the error value to correct co-ordinate values
derived using a probe. In Fig. 11, reference numeral
15 13 denotes the datum point and O is the x-axis offset
to the probe centre-line.

Figs. 12 and 13 are schematic side and plan views of an
automatic lathe with which the present invention may be
20 used. Reference numeral 14 denotes a headstock of the
lathe; reference numeral 15 denotes the lathe spindle;
reference numeral 16 denotes an z-axis lead screw;
reference numeral 17 denotes an z-axis drive;
reference numeral 18 denotes an z-axis encoder;
25 reference numeral 19 denotes an x-axis lead screw;
reference numeral 20 denotes an x-axis drive;
reference numeral 21 denotes an x-axis encoder; and
reference numeral 22 denotes a cabinet within which is
a computerised numerical control unit data processing
30 means. As well as controlling the operation of the
lathe, the data processing means is also programmed to
store co-ordinate positional information and perform
calculations on the basis of the above for determining
the effective diameter or radius of the stylus 5 and
35 the error, if any, between the assumed centre-line of
the lathe and the actual centre-line.

Incidentally, the item 7 could also itself operate as a
touch trigger probe, needing a greater contact force to
cause a triggering reaction than the probe 4, and be
used, for example, in setting up tools carried by the
5   lathe.

There will now be described an extension of the present
invention whereby calibration is repetitively carried
out during operation of the lathe to calibrate for a
10   shift in the actual centre-line of the lathe.
Referring to Fig. 14a, this shows the condition of a
workpiece 23 with the actual centre-line in is correct,
assumed position, Fig. 14b showing the position of
workpiece 23 in a second condition in which the actual
15   centre-line has shifted. In the first condition, the
probe 4 will be referred to the correct centre-line
(axis of rotation) from its datum point and a tool
offset, or a separate data store can be modified to
store the probe offset from the datum point to the
20   centre-line of the probe 4. In the second condition,
the lathe spindle has moved for an unspecified reason
by an unknown amount. The specification of the datum
position with respect to the actual centre-line of the
lathe is no longer valid. A re-calibration for the
25   actual centre-line of the lathe then needs to be
carried out on the basis of the foregoing. Such
re-calibration may be carried out repetitively during a
prolonged sequence of operations to continuously
re-calibrate for a shift in the actual centre-line of
30. the lathe. It will be noted that only the second half
of the procedure described above (calibration for the
centre line) needs to be repeated; the probe itself
will not normally need recalibration since it has been
calibrated against the known dimension of the reference
35   item 6 or 7. It is also to be noted that a subsequent

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calibration of the lathe will be for a specific
position thereon and, if the shift of the centre-line
results in an angular error between the assumed
centre-line and the actual centre-line, then

5   re-calibration may be repeated for different zones -
see Fig. 15 in which, on the basis of a knowledge of
the angular error and the distance offset in the z
direction at the position of the probe 4 at
re-calibration, the errors at zones 24a,24b,24c,24d ...

10   may be calculated by the data processing means. The
errors due to the angular inclination may be made
available for incorporation into an interactive control
system where the software of the data processing means
adjusts readings of positional measurement.

15   Alternatively, the data may be fed out to an external
computer capable of re-adjusting a lathe control system
without the need for compensations or modifications of
positional data.

20   Incidentally, as an alternative to using a particular
item 12, any convenient diameter on an actual workpiece
being operated on may be used for calibration for a
shift in lathe centre-line, as the process is size
independent; or one may provide a nominal diameter

25   which may be destroyed later either on the workpiece
itself or on a fixture on the lathe.

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CLAIMS:

1.   A method of calibration for an automatic machine
tool having workpiece-holding means which is rotatable
for machining a workpiece held therein, data processing
means, and a trigger probe, which probe can be
5   triggered against a point on the surface of the
workpiece, in response to which the data processing
means produces information representative of positional
co-ordinates of the probe at the trigger point, the
co-ordinates being with respect to a datum point which
10 is based upon an assumed axis of rotation of the
workpiece, the method comprising:
        (a)   calibrating the probe, by triggering it against
at least one point on an item having a known dimension
and, using said dimension and a positional co-ordinate
15 of the or each trigger point as indicated by the data
processing means, computing a probe correction offset;
and
        (b)   calibrating the machine tool, by providing a
feature centred with respect to the actual axis of
20 rotation; triggering said probe against first and
second diametrically opposite points on said feature
with respect to the axis of rotation; and, on the basis
of the mean of respective positional co-ordinates of
the trigger points as indicated by the data processing
25 means, corrected by the probe correction offset,
computing an offset related to the difference, if any,
between the actual axis of rotation and the assumed
axis of rotation.

30 2.   A method according to Claim 1, wherein the probe
is calibrated by triggering it against two opposite
points of the item having a known dimension, and
calculating the probe correction offset Db as:
        $Db = Dref - (X1-X2)$

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where Dref is said known dimension, and X1 and X2 are
the co-ordinates of the trigger points as measured by
the data processing means.

5 3.   A method according to Claim 1 or Claim 2,
wherein the feature centred with respect to the actual
axis of rotation is provided by machining the feature
into a workpiece.

10 4.   A method according to any one of the preceding
claims, wherein said offset Xe related to the
difference between the actual axis of rotation and the
assumed axis of rotation is given by

$$Xe = Xc-Xm$$

15 where Xc is the assumed positional co-ordinate of the
axis of rotation, and Xm is said mean of the positional
co-ordinates of the trigger points of said feature
centred on the actual axis of rotation.

20 5.   A method according to any one of the preceding
claims, in which step (b) is repeated at subsequent
times to re-calibrate the machine tool.

6.   A method according to any one of the preceding
25 claims, wherein step (b) is repeated for different
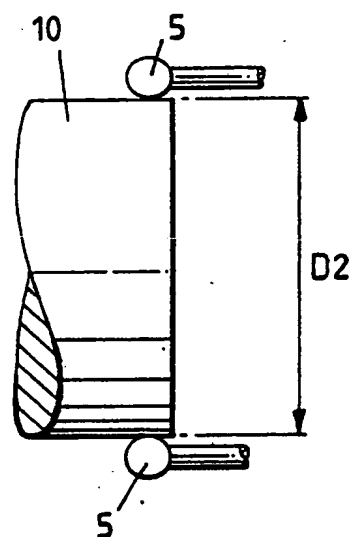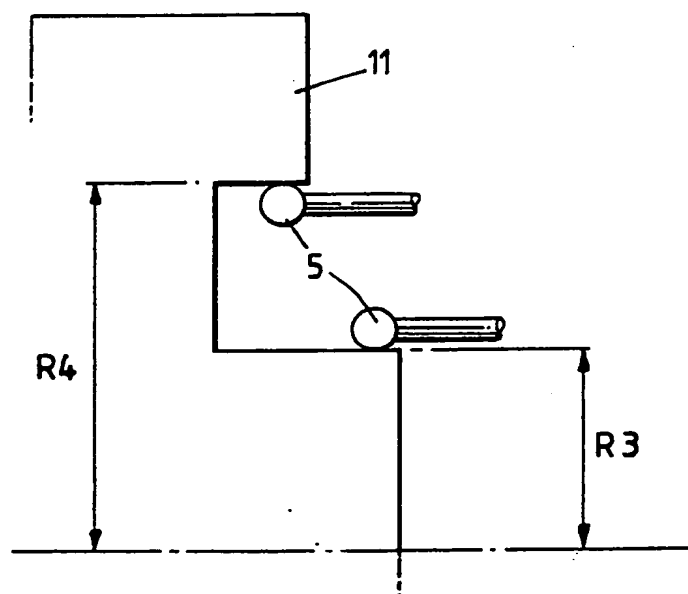working zones of the machine tool.
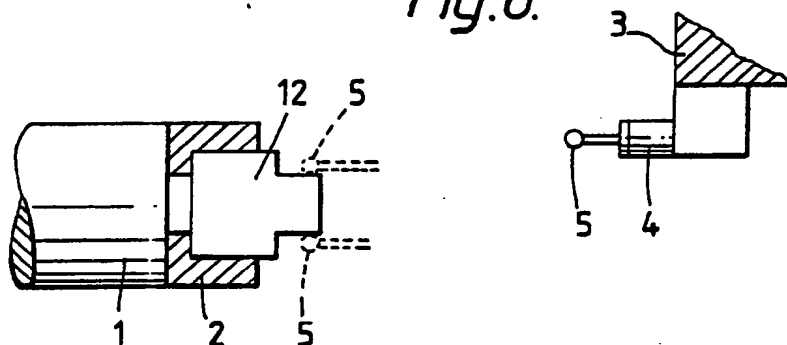
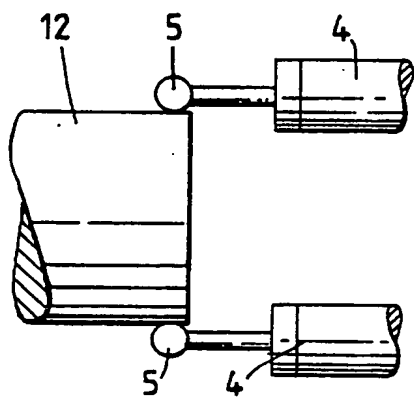Fig.1.

Fig.2.

Fig.3.

Fig.4.
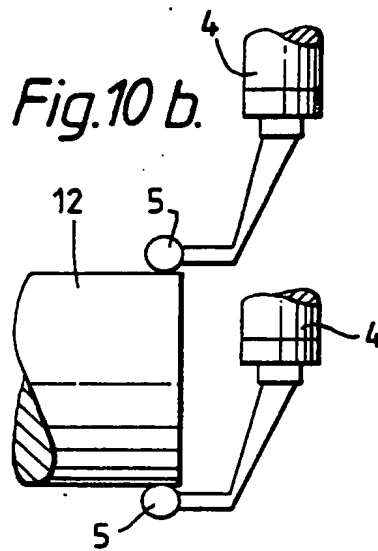
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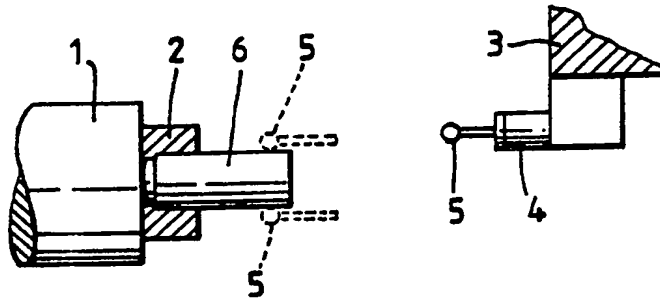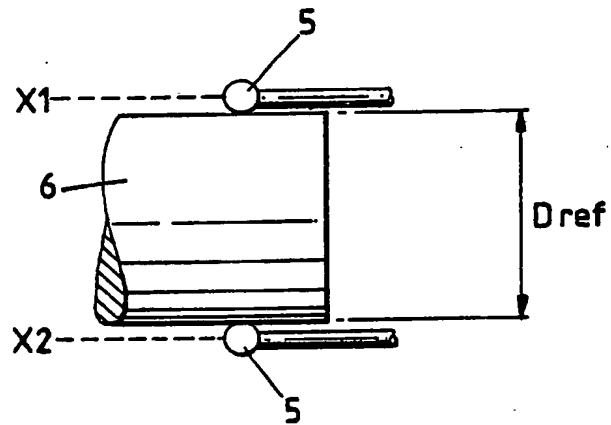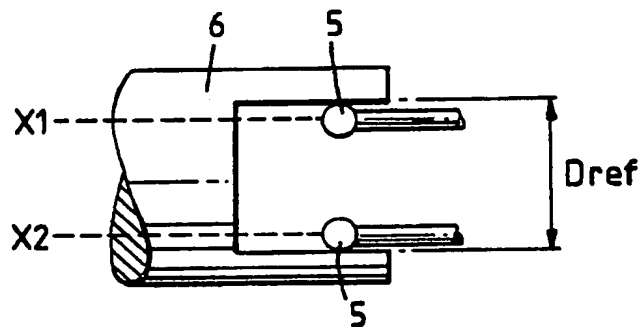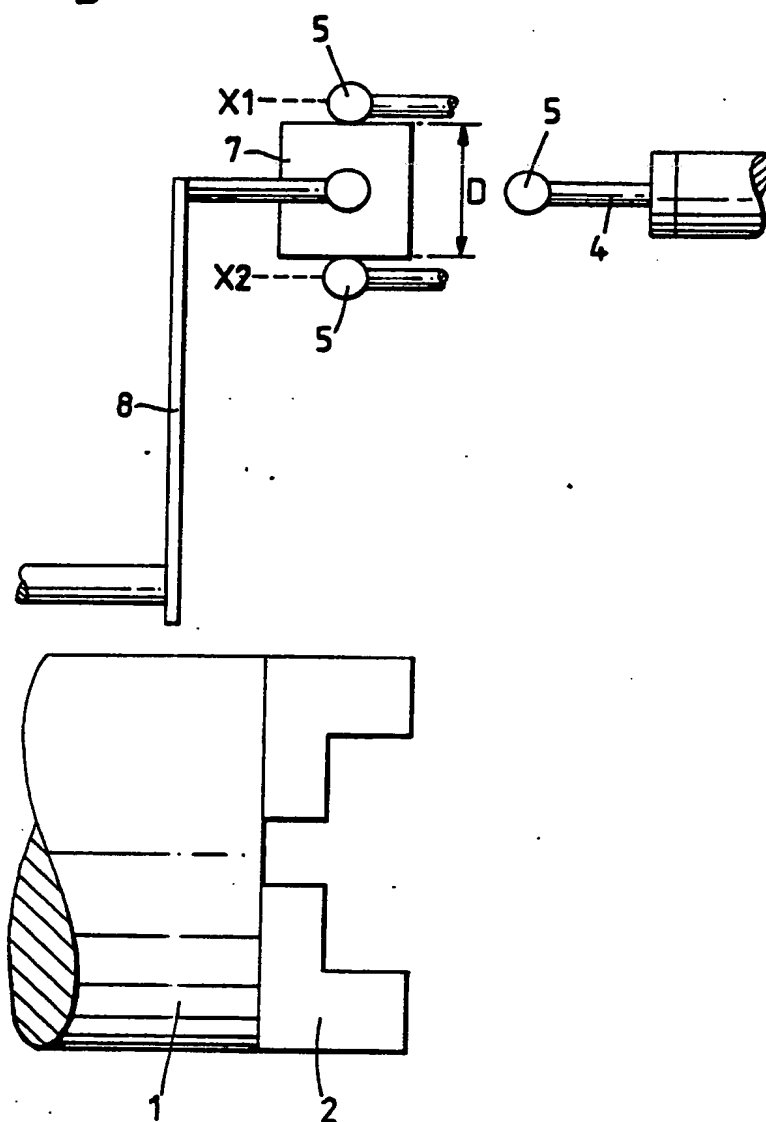
Fig.5.
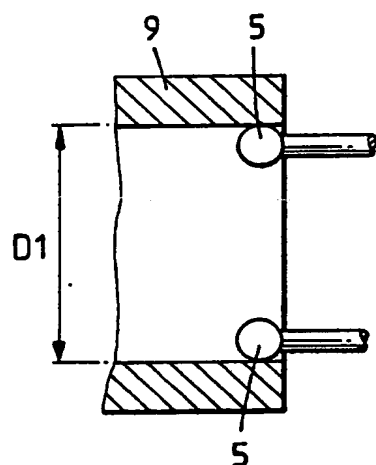
Fig.6.

Fig.7.

Fig.8.

Fig.9.

Fig.10 a.

Fig.10 b.

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Fig.11.

Fig 12

Fig.13.

6/6

Fig.14a.
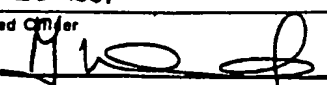
23

3

13

5

4

Fig.14b.

23

3

13

5

4

Fig.15.

23

13

3

5

4

24a   24b   24c   24d   24e

INTERNATIONAL SEARCH REPORT

I. CLASSIFICATION F SUBJECT MATTER (if several classification symbols apply, indicate all) *

According to International Patent Classification (IPC) or to both National Classification and IPC

IPC⁴ :   G 05 B 19/18

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System	Classification Symbols
IPC⁴	G 05 B

Documentation Searched other than Minimum Documentation
to the Extent that such Documents are Included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category *	Citation of Document, ¹¹ with Indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³
X	US, A, 4554495 (DAVIS) 19 November 1985 see the whole document --	1-6
Y	US, A, 4562392 (DAVIS et al.) 31 December 1985 see the whole document --	1-6
Y	GB, A, 2069142 (McMURTRY) 19 August 1981 see the whole document --	1-6
Y	GB, A, 2033610 (ALFRED HERBERT LTD) 21 May 1980 see the whole document	1-6

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* Special categories of cited documents: ¹⁰
"A" document defining the general state of the art which is not considered to be of particular relevance
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"P" document published prior to the International filing date but later than the priority date claimed

"T" later document published after the International filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
18th November 1987	1 1 DEC 1987

International Searching Authority	Signature of Authorized Officer
EUROPEAN PATENT OFFICE	M. VAN MOL

Form PCT/ISA/210 (second sheet) (January 1985)

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON

INTERNATIONAL APPLICATION NO.   PCT/GB 87/00644 (SA   18637)
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This Annex lists the patent family members relating to the
patent documents cited in the above-mentioned international
search report. The members are as contained in the European
Patent Office EDP file on 26/11/87

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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
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		FR-A-	2569597	07/03/86
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